

# **Dual Frequency Scatterometer Ocean Surface Vector Wind Mission**

## ***1. Science Requirements Document***

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## **1. Introduction**

This document presents an overview of the objectives of the Dual Frequency Scatterometer (DFS) Ocean Vector Wind Mission (OVWM), and defines its science requirements, success criteria, and standard data products.

This document draws from previous community wide efforts to define the operational and scientific needs for ocean surface vector winds. The operational needs have been documented by Chang and Jelenak [2006, 2008]. The climate needs were reviewed in the National Research Council (NRC) decadal review [NRC, 2007]. A community workshop to validate the DFS climate requirements is planned for mid-2009.

### **1.1. Background**

The operational use of satellite ocean surface vector wind (OSVW) observations has advanced considerably over the past decade. OSVW data from research (QuikSCAT and WindSat) and operational (ASCAT) satellite systems are now as a critical tool utilized daily by operational weather forecast and warning centers around the world. Of these systems, NASA's QuikSCAT, which provides the highest quality global OSVW measurements, the finest spatial resolution, and the most complete coverage with 90% of the world's oceans covered in a single day, has had the largest impact in operational weather forecasting and warning.

In addition to being essential for operational weather forecasting, OSVW are key for understanding the Earth's climate. After nearly 10 years of continuous observation, QuikSCAT has provided the first consistent global OSVW climate data record to date, and constitutes the baseline for the study of the drivers of climate change over the ocean. The DFS, with its QuikSCAT heritage, will continue and improve upon the collection of this essential climate data record.

#### **1.1.1. Operational Applications**

Within NOAA's National Weather Service (NWS), the use of OSVW encompasses the warning, analysis, and forecasting missions associated with tropical cyclones (TC), extratropical cyclones, fronts, localized coastal wind events (e.g., gap winds, barrier jets), and the forecast of sea conditions driven by winds. Today, OSVW measurements are an intrinsic part of everyday forecasting and warning processes at NWS operational centers and offices.

The near real time QuikSCAT wind data have had major operational impact in the areas of:

- Determination of wind warning areas for mid-latitude systems (Gale, Storm, Hurricane Force [HF]); Specifically, the availability of reliable, spatially extensive QuikSCAT measurements allowed the introduction of mid-latitude HF

wind warnings starting in late 2000 (Von Ahn et al. 2006; Chang and Jelenak 2006; Jelenak and Chang 2008).

- From Fall 2006 through spring 2007, the Ocean Prediction Center (OPC) identified and issued warnings for 115 separate extratropical cyclones (64 events in the Atlantic and 51 in the Pacific) that reached HF intensity (wind speeds  $\geq 64$  kts). While many of these cyclones spend their entire lives at sea, over the last several seasons HF conditions produced by extratropical ocean storms have impacted the coasts of Alaska, the Pacific Northwest, and New England.
- Determination of TC 34-knot and 50-knot wind radii.
  - In an attempt to quantify the utility of QuikSCAT in operational TC analysis and forecasting at NHC, Brennan et al. [2009] examined how often QuikSCAT data were mentioned in NHC's TC discussion (TCD) products. One TCD is issued for each active TC with every routine 6-hourly forecast package, and for occasional "special" advisories. When QuikSCAT data are available for a TC, they are referenced 40-50% of the time in TCDs.
- Tracking of TC center location, including the initial identification of TC formation (Brennan et al. 2008).
- Identification and warning of extreme gap and jet wind events at all latitudes;
  - 73% of the storm-force wind events in the Gulf of Tehuantepec were identified solely through the use of QuikSCAT measurements during the period of October 1999 to January 2007 at NHC (Chang and Jelenak 2006, Jelenak and Chang 2008).
- Current location of frontal systems and high and low pressure centers;
  - QuikSCAT OSVW is often the only way for forecasters to analyze frontal position in the Gulf of Alaska or Bering Sea. At the NWS Anchorage Weather Forecasting Office (WFO), QuikSCAT winds are utilized 70% of the time for the wind intensity estimates in the warnings it issues (Chang and Jelenak 2006, Jelenak and Chang 2008).
- Improved coastal surf and swell forecasts (Chang and Jelenak 2006, Jelenak and Chang 2008).

The availability of near real-time satellite OSVW data has revolutionized operational marine weather warnings, analyses, and forecasting. To maintain the significant improvements in operational weather forecasting and warning capability that have been realized from QuikSCAT OSVW data, NOAA requires continuity of the OSVW data stream at a level that is equivalent to or better than that currently provided by QuikSCAT

### **1.1.2. Climate Applications**

A consistent, global, and accurate OSVW climate data record (CDR) is essential for understanding global climate change. Winds at the ocean surface and the associated surface wind stress, are key ingredients in driving the circulation of the oceans, coupling sea surface temperature and the atmosphere, modulating the fluxes of energy and gases into the ocean, and in global climate phenomena, such as the El Niño/Southern Oscillation (ENSO). Scatterometers are also key sensors for measuring the evolution of sea ice, one of the main determinants of the Earth's albedo and heat uptake in the Arctic. We briefly examine each of these contributions below.

**Ocean Circulation and Climate Change:** Global sea level rise is due to two components: fluxes of water into the oceans and steric sea level rise due to heat induced expansion of the ocean's volume. The pattern of steric sea level rise is dynamic, as it can be redistributed by the ocean's circulation, which in turn is driven by wind stress, the flux of momentum from atmospheric winds into the ocean. The observation of the modulation of large-scale ocean sea level by winds has been enabled by the availability of a decade-long scatterometer wind data record. As an example of this coupling, Lee and McPhaden [2008] observed decadal tendencies in sea level in much of the Indo-Pacific domain and that could be explained by changes in the driving OSVW. Continuation of the CDR will enable continued observation and better understanding of the adjustment of the global circulation, and sea level rise, to changes in heat uptake by the ocean.

In addition to driving large-scale ocean circulation patterns, winds are responsible for much of the mixing of heat and meridional turbulent heat transport in the ocean. As an example, Emanuel [2001] has hypothesized that TCs are a key ingredient to mixing and meridional heat transport by the oceans. Studies by Chelton and colleagues [2004, 2009] have shown how sea surface temperature features modulate winds, which in turn modulate the ocean eddies, resulting in a coupled ocean-atmosphere system which has different heat dissipation characteristics than a decoupled system, which most climate models currently assume.

**Modulation of Climate by Ocean-Wind Coupling:** Sea surface temperature fronts can have large scale effects on the Earth's atmosphere, beyond simple modulation of the marine boundary layer. Minobe et al. [2008] have shown that, for the Gulf Stream, these interactions, which can be observed in the convergence of ocean vector winds, propagate deep into the troposphere and can exhibit global climate signatures.

**Gas Fluxes into the Ocean:** Ocean vector winds are one of the primary determinants in the uptake of gases, such as the greenhouse gas CO<sub>2</sub>, into the ocean. One of the key unknowns in predicting global climate change is the rate of uptake by the oceans of greenhouse gases, since the oceans constitute their primary sink (for the moment). Winds are also a primary factor in the evaporation of water vapor from the oceans, another key player in global climate change. Yu et al. [2007, 2009] have examined the trends in evaporation and wind speed from scatterometer data. Although the data record is not yet sufficiently long, a plausible correlation can be inferred from these data.

**El Niño/Southern Oscillation:** Westerly wind bursts, observed by scatterometer data, are believed to be key ingredients in the initiation of ENSO events. In addition, the nearly decade-long scatterometer record has allowed the observation of global wind phenomena associated with ENSO events. For instance, Milliff et al. [20] identify an ENSO warm events (WE) precursor signal in strong WE years which occurs just after the so-called Spring Predictability Barrier, providing very early warning of an ensuing ENSO WE.

The nearly decade-long QuikSCAT ocean vector winds data record have also enabled, for the first time, a number of climatologies that characterize winds over the ocean.

- The five-year interactive Climatology of Global Ocean Winds (August 1999-July 2004) shows that persistent small-scale features resolved by the QuikSCAT data make evident “topographic, SST gradient, and ocean current influences on surface winds” (Risien and Chelton 2006, 2008). This climatological data set includes QuikSCAT measurements of wind speed and direction as well as their spatial derivatives: wind divergence and stress curl.
- The seven-year high wind monthly atlas reveals how frequently high winds occur over the open global oceans (Sampe and Xie [2007]). High winds play an important role in Earth’s climate; they remove heat from the ocean, leading to the formation of “deep water” cold, salty, dense water that helps drive global ocean circulation patterns. High winds also help exchange gases, such as CO<sub>2</sub>, between the oceans and the atmosphere, mix different types of ocean water, and pump nutrients up from the deep sea for plankton to feed on.
- The first climatology of the wind power available over the oceans from QuikSCAT data was generated by Liu et al. [2008]. This data set revealed regions of high wind power associated with flow distortion by land, wind channeled by land topography, and buoyancy effect on turbulent stress driven by ocean fronts. These results are of importance for the generation of electricity by ocean wind farms.

**Sea Ice:** In the last decade QuikSCAT has measured the fastest decrease in Arctic sea ice coverage on record [Nghiem, 2008]. Although melting sea ice does not change global sea level, a significant change in sea ice cover changes the Earth’s albedo, as well as fluxes and turbulent mixing in the Arctic ocean. Scatterometer data can map sea ice extent and ice age at spatial and temporal resolutions consistent with climate modeling needs.

### 1.1.3. Dual Frequency Scatterometer

In response to the community’s requirements for a full-performance ocean vector winds measurement capability, a Dual Frequency Scatterometer (DFS) was proposed and accepted as the GCOM-W2 baseline scatterometer. The DFS instrument concept design uses the synergy between Ku-band and C-band scatterometers. The Ku-band scatterometer continues the QuikSCAT heritage in order to preserve wide-swath measurements, high temporal sampling capabilities, and achieve higher spatial resolution.

The C-band scatterometer (ASCAT heritage) provides much more accurate measurements in rain and achieve better performance in all wind speed ranges. The DFS is designed as a scanning pencil-beam scatterometer with a 360° field of view similar to QuikSCAT. The two incidence angles will be chosen to preserve the 1800-km wide swath at the GCOM-W2 altitude. Additional DFS details are:

- Ku-band real-aperture radar operating at 13.4-GHz frequency at two polarizations (V and H) and two incidence angles.
- C-band real aperture type radar operating at 5.4-GHz frequency at H-polarization and two incidence angles.

#### **1.1.4. Near all-weather capability**

Experience with QuikSCAT has shown that wind estimates derived exclusively from Ku-band observations are significantly degraded by rain, leading to inaccurate retrievals in some rainy conditions and an inability to measure maximum winds near the centers of tropical and extratropical cyclones and in areas of convection. Rain has three effects that corrupt both the wind speed and direction determinations. Low rain rates attenuate the signal, while higher rain rates enhance backscatter from the rain drops. There is also a splash effect that results in increased backscatter from the rain drops striking the ocean surface. Scattering from rain is direction independent, and so in addition to corrupting the amplitude, which mainly determines speed, the wind direction determination is also compromised by rain. SeaWinds with AMSR on ADEOS-II allowed a detailed physical and empirical investigation of these effects. It is also known from the C-band scatterometers on ERS-1 and 2 and the recently launched EUMETSAT ASCAT that retrievals at that frequency are much less sensitive to rain.

#### **1.1.5. High wind retrieval capability**

Scatterometry relies on a geophysical model function (GMF) that relates radar backscatter to wind speed and direction. The GMF relationship of backscatter and wind depends on radar parameters such as frequency, incidence angle, and polarization. Esteban-Fernandez et al. [2006] utilizing aircraft Ku and C-band scatterometer measurements showed the fundamental behavior of the GMF for Ku- and C-bands at HH and VV polarization (i.e., same transmit and receive polarization), and several incidence angles (angle from the normal to the surface) for winds higher than 20 m/s. Their results for the first time revealed that the backscatter at Ku-band stops increasing for wind speeds above about 40 m/s, while the backscatter at C-band and HH polarization continues to increase. Thus, adding C-band will provide significantly improved high wind speed performance.

## **1.2. Operational and Science Objectives**

To support wind forecasting and warning services and products and to provide ocean surface wind vector data for assimilation into numerical weather prediction models the objective is to:

- Acquire and distribute in near real time all-weather, high-resolution measurements of near-surface winds over the global oceans

To support climate services and research the objective is to:

- Provide ocean surface wind vector measurements needed to document, heat uptake, transport, and release by the ocean, ocean carbon sources and sinks (ocean surface vector winds modulates air-sea exchanges of gases such as CO<sub>2</sub>) and air-sea exchange of water and the ocean's overturning circulation

## **2. Scope**

This document describes the highest level science requirements governing the performance of the DFS OVW Mission. It provides the basis for other lower level documents which will define the flight instrument and ground data system requirements. In addition to the requirements, this document includes constraints and guidelines on instrument concept evaluation and prelaunch and postlaunch performance estimation approaches.

## **3. Definitions**

### **3.1. Requirement**

A "requirement" as used in this document specifies a condition, parameter, or capability with which the system design must be compliant, verifiable, and have a demonstrated achievement during the mission. All requirement statements are preceded by the word "Requirement" and use the verb "shall". The term requirement encompasses the requirements of both the research and operational weather forecasting and warning communities.

### **3.2. Goal**

A "goal" as used in this document specifies a condition, parameter, or capability with which the system design will strive to be compliant but it is not mandatory that such compliance be verifiable or have a demonstrated achievement during the mission. Mandatory compliance or demonstrated achievement are not required because the capabilities in the DFS or GCOM-W2 systems limit the performance, because the inherent technical difficulty with the achievement is too great, or because the cost of achievement is too large. Nevertheless, a goal is tracked like a requirement so if resources or capabilities permit compliance, better system performance will result. All goal statements are preceded by the word "Goal" and use the verb "will".

### **3.3. Minimum, Full, and Extra Success Criteria**

The DFS meets its minimum success criteria if it meets the minimum mission requirements given below. The DFS meets its full success criteria if it meets the nominal mission requirements given below. The DFS meets the extra success criteria if it meets the nominal mission requirements and goals given below. The minimum, full, and extra success criteria are given to be consistent with JAXA mission success terminology.

### **3.4. True Wind**

Throughout this document, the term "true wind" refers to the equivalent neutral wind at a height of 10 m above the ocean surface. Equivalent neutral wind is the surface-relative wind that would result in the observed stress if the atmosphere were neutrally stratified.

### **3.5. Wind Vector Cell (WVC)**

A wind vector cell (WVC) is a region of the ocean surface used as the nominal spatial estimation cell. Backscatter measurements are assigned to a given resolution cell based on the amount of overlap between the measured radar cross section slice and the WVC area.

### **3.6. Accuracy**

The "accuracy" of the wind speed and direction, calculated from the DFS OVW measurements, is the root-mean-square (RMS) difference between the retrieved wind and the true wind in the cell. In this document, accuracy specifications will be stated separately for speed and direction, although it is well known that many applications of DFS OVW data will involve use of the wind velocity data, thereby coupling the wind speed and wind direction measurements and combining their errors in nonlinear ways.

### **3.7. Geophysical Model Function**

A "geophysical model function" is a function relating measurement polarization, incidence angle, wind speed, and relative wind direction to the radar backscatter coefficient.

## ***4. Assumptions and Constraints***

### **4.1. [Requirement] The DFS instrument shall fit within the accommodation constraints of the GCOM-W2 mission.**

Due to the capabilities of the expected GCOM-W2 platform and accommodation constraints with the AMSR instruments, it is expected that the DFS instrument will have

to limit its science goals. The NOAA users specified an initial set of requirements [Chang and Jelenak, 2006]. These requirements are modified by this document to a new set that will still make a significant advance to NOAA's weather forecasting capabilities. JAXA, NOAA, and NASA shall agree upon accommodation constraints. Accommodation constraints may include, but are not limited to:

- Orbit altitude and inclination
- Field of view of payload or spacecraft instruments
- Mass, inertial moments, residual inertial disturbances, power, or data rate
- Interference requirements between the payload instruments

When a suitable accommodation cannot be found without degrading the ability of AMSR or DFS to achieve its requirements or goals, the science team shall evaluate the engineering accommodation solutions and recommend those that best satisfy the goals of the entire GCOM-W2 mission.

**4.2. [Assumption] Prior to launch, the ability of the DFS to meet the science requirements will be assessed based on the best available data, as agreed upon with the science team.**

There are requirements on the DFS for situations, such as very high winds or rain, where experimental data, such as the geophysical model function, may be sparse. For the purpose of evaluating the pre-launch ability of the DFS to meet the science requirements, the science team will work with the project to select a nominal data set sufficient for assessing the pre-launch performance of the instrument. Examples of pre-launch assumed data are the geophysical model function and the effects of rain upon the radar signal at Ku and C-bands.

## ***5. Nominal, Enhanced, and Minimum Missions***

Requirements for the DFS mission on GCOM-W2 are categorized into three levels: Mission Goals (MG), Nominal Mission (NM) Requirements and Minimum Mission (MM) Requirements. The Nominal Mission forms the basis for the initial Project Implementation Plan and the requirements shall be achieved unless the resources of the Project are insufficient to accomplish them. Compliance with the NM requirements will result in Full Success, as defined above. Descoping to the Minimum Mission (MM) requirements will be exercised only when the resources of the Project are insufficient to implement the NM and only after other descope options have been explored. Compliance with the Minimum Mission will result in Minimum Success, as defined above. Mission Goals are defined here so that the DFS engineering team can decide how to make trades and where to apply resources that might otherwise go unused in the pursuit of enhanced science or operational products. Important examples of Mission Goals are those related to the joint products of the DFS and AMSR instruments. Compliance with the Mission Goals will result in Extra Success, as defined above.

Unless otherwise indicated, requirements are written to reflect the Nominal Mission.

## **6. DFS Payload**

### **6.1. [Requirement] Nominal DFS Payload**

The payload required to complete the nominal DFS mission shall consist of a 4-channel pencil-beam scatterometer. The channels will be paired into two inner beams and two outer beams, consistent with the swath requirement (8.2). Each pair shall be composed of a Ku-band beam and a C-band beam.

### **6.2. Minimum DFS Payload**

The payload required to complete the minimum DFS mission shall consist of a 2-channel pencil-beam scatterometer. The channels will be paired into one Ku-band inner beam and one Ku-band outer beams. The capabilities of the minimum payload shall be equal to those for the QuikSCAT scatterometer.

## **7. Mission Lifetime**

### **7.1. [Requirement] Nominal Mission Lifetime**

The nominal mission lifetime shall be 5 years.

### **7.2. [Requirement] Minimum Mission Lifetime**

The minimum mission lifetime shall be 3 year.

### **7.3. [Goal] Goal Mission Lifetime**

The goal for the mission lifetime will be 7 years.

## **8. Space/Time/Angular Sampling Requirements**

### **8.1. [Requirement] Temporal Sampling Requirement**

The DFS shall measure at least 85% [TBC] of the Earth's oceans each day. This requirement is needed to meet forecasting and research temporal sampling requirements. This specification includes data loss from the instrument.

## **8.2. [Requirement] DFS Swath**

The DFS swath shall be greater than, or equal to, 1800 km of continuous data. This requirement is needed to insure that data coverage gaps, such as a nadir gap, do not occur while still meeting the 90% temporal sampling requirements. Gaps in the swath coverage have negative impacts on meeting operational and science requirements.

## **8.3. [Requirement] GCOM-W2 Orbit Height**

The GCOM-W2 orbit shall be such that the scatterometer look angle shall not exceed  $49^\circ$  (TBC) or be less than  $40^\circ$  (TBC) while remaining consistent with the minimum swath requirement. This look angle limitation is required to make use of heritage wind model functions. In practice, this will limit the GCOM-W2 orbit to be in the approximate range  $\sim 700$  km to  $\sim 800$  km. This requirement is imposed by the desire to restrict the geophysical model function to similar angles as observed by QuikSCAT, which share scattering physics and brightness characteristics.

## **8.4. [Requirement] The incidence angle range shall not exceed $0.7^\circ$ ( $3\sigma$ ) for any scatterometer beam.**

## **8.5. [Goal] The incidence angle range will not exceed $0.3^\circ$ ( $3\sigma$ ) for any scatterometer beam.**

The geophysical model function varies as a function of incidence angle and will have to be fully determined after launch, since it is expected that the incidence angles used by the DFS will differ from those used QuikSCAT due to the change in orbit altitude. The time required to determine this model function, and hence the time prior to the DFS operational phase, is proportional to the range of incidence angles viewed by the payload. Geocentric spacecraft pointing (used by the GCOM-W1 platform) will impose a minimum variability of  $\sim 0.4^\circ$  in the incidence angle, due to the ellipticity of the Earth. This limits the spacecraft and payload pointing control budget to  $0.3^\circ$ . If geodetic (i.e., nadir look angle perpendicular to the ellipsoid) spacecraft pointing is selected, the variability of look angles due to the geoid slope variability is substantially mitigated.

# **9. Data Products, Distribution, and Archiving**

## **9.1. [Requirement] Standard Products**

The mission shall produce the following standard data products:

**Level 0** Raw data products. Frame synchronized, time ordered, gap filled, non-redundant scatterometer telemetry with additional data needed for processing. Additional data includes instrument engineering data and spacecraft attitude, ephemeris, and time correction data.

**Level 1A** Engineering data products. Instrument telemetry time tagged and converted to Engineering Units converted as required, organized by GCOM-W2 orbital revolution (begins at South Pole). Supplemental data includes instrument calibration data.

**Level 1B** Global calibrated backscatter coefficients. All instrument measurements converted to normalized radar backscatter coefficients with instrument calibration applied. Backscatter coefficients for high resolution elements (slices) are provided along with Earth location and error estimates.

**Operational Merged Geophysical Data Records (OMGDR's):** These data records will be produced in real time and used for operational weather applications. These records will be produced in Binary Universal Form for the Representation of meteorological data (BUFR), a binary data format maintained by the World Meteorological Organization and used widely by operational weather agencies. The OMGDR's will not be archived or reprocessed.

Fields contained in the OMGDR's shall include (but not be restricted to):

- Backscatter coefficients with information needed for wind retrieval reorganized into WVC's. Backscatter coefficients may be composites of slices from a single pulse that fall within a WVC. Backscatter coefficients have clear sky absorption correction, rain contamination attenuation and scattering correction.
- When collocated AMSR, or DFS, radiometer data are available, brightness temperatures are included.
- Geolocated multiple (ambiguous) wind vectors in each ocean WVC with a flag for the selected vector. Wind vectors are retrieved from composite backscatter measurements in a WVC using the Geophysical Model Function.
- Collocated wind error estimates and flags indicating data quality.

**Science Merged Geophysical Data Records (SMGDR's):** These data records contain the climate quality data records. They contain the same fields as the OMGDR's, but may have improved calibration, flagging, or geolocation relative to the OMGDR's. The SMGDR's will be stored in a data format widely used by the scientific and climate community, such as NetCDF or HDF5. These data are archived and reprocessed as improved calibration, geophysical model functions, flagging, or processing algorithms become available. The data set will form a consistent, uniformly calibrated and processed climate data record collected by the DFS for the entire GCOM-W2 mission.

## **9.2. [Goal] Additional Data Products**

The project will produce the following data on a best effort basis:

- **Sea Ice Mask:** A geolocated mask of sea ice extent, classified into first year or multi-year ice. The sea ice mask will also include icebergs. This product is produced for each radar pass and as a weekly global mosaic.
- **Normalized Radar Cross Section Imagery:** Composite imagery for each radar polarization and frequency, including average cross-section and cross section variability. This product is produced for each radar pass and as a weekly global mosaic.
- **Higher Resolution Wind Vector Storm Sector Products:** For tropical cyclones and other storms, it is possible to generate useful winds information at higher resolution than the nominal data. These higher resolution data will be generated for all tracked cyclones and storms at a resolution of at least 5 km. The data will be available in near real time, and will be archived to facilitate climate studies.
- **Coastal wind data product:** Near the coasts, it is possible to produce a Ku-band only wind data product that rejects slices contaminated by land to produce wind estimates closer to the coast. This data product will not have the same performance characteristics as the nominal wind data product, may not be produced in regions of adverse geometry, and is not all-weather. Nevertheless, it may be of significant benefit for coastal warnings and shipping applications. The coastal data product will be reported on an irregular grid, which minimizes land contamination.

### **9.3. [Requirement] Raw Data Latency**

The raw data shall be received at the ground stations within 100 minutes of data collection. This corresponds to one data download/revolution.

### **9.4. [Requirement] OMGDR Processing Latency**

The OMGDR data products shall be available for use within 80 minutes of downlink to the ground station.

### **9.5. [Goal] OMGDR Processing Latency**

The OMGDR data products will be available for use within 60 minutes of downlink to the ground station.

### **9.6. [Requirement] SMGDR Processing Latency**

For nominal processing, the SMGDR data products shall be available within 1 day of downlink to the ground station. Reprocessed SMGDR data for the entire mission to date shall be available within 6 months of the start of reprocessing.

### **9.7. [Requirement] Operational Data Distribution**

OMGDR data shall be made available by NOAA to other selected operational agencies, via FTP within TBD minutes of product generation.

### **9.8. [Requirement] Science Data Distribution**

SMGDR data shall be made freely available to the science community through a public distribution center (such as NASA's PODAAC) within 1 day of SMGDR processing.

### **9.9. [Requirement] Data Archiving**

The data products for the entire mission, excluding the OMGDR's, shall be archived. The data to be archived include metadata required for reprocessing and calibration of the data.

### **9.10. [Requirement] Data Reprocessing**

If significant changes (as determined by the science team) in the data product occur as a result of improved algorithms or calibration, the science data shall be reprocessed and made publicly available for the entire mission duration. A maximum of TBD reprocessing events shall occur during the nominal mission. These changes will be publicly available in documented form, including a version number that is included as metadata in the achieved data files.

## **10. Wind Vector Measurement Requirements**

For ease of reference, Table 1 below summarizes the driving performance and sampling characteristics for the DFS nominal wind vector products and the minimum mission.

| <b>Requirement</b>        | <b>NOAA 2006 User Goals</b>                         | <b>Minimum Payload</b>                                        | <b>Nominal DFS</b>                                                        |
|---------------------------|-----------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|
| WVC Size                  | <5 km                                               | 12.5 km                                                       | <10 km                                                                    |
| Coastal Mask              | <5 km                                               | 20 km                                                         | <10 km                                                                    |
| Coverage                  | 90% of the ocean surface every 24 hours             | 90% of the ocean surface every 24 hours                       | 90% of the ocean surface every 24 hours                                   |
| Wind Speed Accuracy (RMS) | 3-20 m/s: 1 m/s<br>20-30 m/s: 10%<br>30-80 m/s: 10% | 3-20 m/s: 2 m/s<br>20-30 m/s: 10%<br>30-80 m/s: not specified | 3-20 m/s: 2 m/s<br>20-30 m/s: 10%<br>30-50 m/s: 10%<br>50-80 m/s: 20%goal |

|                               |                                             |                                            |                                                        |
|-------------------------------|---------------------------------------------|--------------------------------------------|--------------------------------------------------------|
| Wind Direction Accuracy (RMS) | <b>3-30 m/s: 10°<br/>30-80 m/s: 10°</b>     | 3-30 m/s: 20°<br>30-80 m/s: no requirement | 3-30 m/s: 20°<br>30-50 m/s: 20°<br>50-80 m/s: 30° goal |
| Retrieval in Precipitation    | <b>All-weather wind retrieval</b>           | None in heavy precipitation                | Near all-weather wind retrieval                        |
| Product Latency               | <b>&lt; 180 minutes for 85% of the data</b> | < 180 minutes for 85% of the data          | < 180 minutes for 85% of the data                      |

**Table 1:** Summary of DFS sampling and performance requirements for the minimum mission (3<sup>rd</sup> column) and the nominal DFS mission (4<sup>th</sup> column). For reference, the second column presents the long term goals for NOAA ocean vector winds measurements, as documented in Chang and Jelenak [2006]. These goals serve as a guiding principle for the DFS design.

### 10.1. Wind Vector Solutions

Multiple solutions may be reported for each WVC. A single wind vector solution shall be identified as the "selected" solution for each WVC. The wind speed and wind direction requirements are specified for the selected solution.

### 10.2. [Requirement] Wind Speed Accuracy

The wind speed accuracy, as defined in 3.6, and for a WVC size <10 km, shall be:

- No requirement for wind speeds less than 3 m/s
- 2 m/s for wind speeds between 3 m/s and 20m/s
- Less than 10% of the true wind speed, for wind speeds >20 m/s and <50 m/s.

### 10.3. [Goal] High Wind Speed Accuracy

The wind speed accuracy, as defined in 3.6, and for a WVC size <10 km, and wind speeds between 50 m/s and 80 m/s will be 20% of the true wind speed.

### 10.4. [Requirement] Wind Direction Accuracy

The wind direction accuracy, as defined in 3.6, and for a WVC size <10 km, shall be:

- No requirement for wind speeds less than 3 m/s
- <20° for wind speeds between 3 m/s and 50m/s

### **10.5. [Goal] High Wind Direction Accuracy**

The wind direction accuracy, as defined in 3.6, and for a WVC size <10 km, and wind speeds between 50 m/s and 80 m/s will be 30°.

### **10.6. [Requirement] Minimum Mission Wind Speed Accuracy**

The minimum mission wind speed accuracy, as defined in 3.6, and for a WVC size of 12.5km, shall be:

- No requirement for wind speeds less than 3 m/s
- 2 m/s for wind speeds between 3 m/s and 30m/s
- No requirement for wind speeds >30 m/s

### **10.7. [Requirement] Minimum Mission Wind Direction Accuracy**

The minimum mission wind direction accuracy, as defined in 3.6, and for a WVC size of 12.5km, shall be:

- No requirement for wind speeds less than 3 m/s
- <20° for wind speeds between 3 m/s and 30m/s
- No requirement for wind speeds >30 m/s

### **10.8. [Goal] Climatological Wind Vector Biases**

The biases on seasonally averaged winds will be less than TBD% of the seasonal mean in magnitude and TBD% of the seasonal mean in direction. The biases on seasonally averaged wind stress will be less than TBD% of the seasonal mean in magnitude and TBD% of the seasonal mean in direction. This climate goal is not easily verified on a global basis, and is therefore not levied as a requirement on the system.

### **10.9. [Requirement] Footprint and Slice Size for the Nominal Mission**

The 3dB, two-way, antenna footprint size in the azimuth direction shall be:

- < 15km for Ku-band
- < 35km for C-band

The downlinked slices shall have a dimension of <3km in the range direction.

These intrinsic instrument resolutions are required to meet the accuracy and WVC cell size requirements in near all weather. They are driven by accommodation constraints.

#### **10.10. [Requirement] Footprint and Slice Size for the Minimum Mission**

The minimum mission 3dB, two-way, antenna footprint size in the azimuth direction shall be <25 km. The downlinked slices shall have a dimension of <6 km in the range direction. These numbers are consistent with the QuikSCAT mission.

#### **10.11. [Requirement] Geolocation Accuracy**

The center location of each measurement slice shall be known to an accuracy of 1 km [TBC] in a geolocated coordinate system.

Need to add orbit req

#### **10.12. [Requirement] WVC Grid Size for Nominal Mission**

The WVC grid size, as defined in 3.5, shall be 10km or less for the required nominal mission products.

#### **10.13. [Goal] WVC Grid Size for Nominal Mission**

The WVC grid size, as defined in 3.5, shall be 5 km or less for the “goal” nominal mission products.

#### **10.14. [Requirement] WVC Grid Size for the Minimum Mission**

The WVC grid size, as defined in 3.5, shall be 25 km or less for the required nominal mission products.

#### **10.15. [Requirement] Performance in Rainy Conditions**

The DFS shall meet the measurement accuracy requirements for rain rates less than or equal to TBD.

#### **10.16. [Requirement] Minimum Performance in Rainy Conditions**

The DFS shall meet the measurement accuracy requirements for rain rates less than or equal to TBD in order to meet the minimum mission requirements.

#### **10.17. [Goal] Goal Performance in Rainy Conditions**

The DFS will meet the measurement accuracy requirements for rain rates less than or equal to TBD

#### **10.18. [Requirement] Nominal Mission Performance in Coastal Regions**

The DFS shall meet the measurement accuracy requirements within 15 km of the coast.

### **10.19. [Requirement] Minimum Mission Performance in Coastal Regions**

The DFS shall meet the measurement accuracy requirements within 20km of the coast.

### **10.20. [Goal] Goal Performance in Coastal Regions**

The DFS shall meet the measurement accuracy requirements within 10km of the coast.

### **10.21. [Requirement] Land, Rain, and Ice Flags**

Radar backscatter data not suitable for accurate wind retrieval due to land, precipitation, or ice contamination shall be flagged appropriately. The data flag shall be accurate 90% of the time.

### **10.22. [Requirement] Wind Error Estimates**

Each retrieved wind direction and speed estimate shall have associated with it a formal estimation error estimate. Wind vectors that are not expected to meet the accuracy requirements shall be flagged accordingly.

## **11. Calibration/Validation Requirements**

### **11.1. [Requirement] Performance Validation**

The DFS performance shall be validated independently during the validation phase. Validation shall include, but not be limited to:

- Comparison against available *in situ* wind measurements, such as those provided by ocean buoys or suitably instrumented ships.
- Comparison against *in situ* data collected by airborne sensors. These data are expected to be crucial for validation of performance for high winds and rainy conditions.
- Statistical comparisons against regional or global numerical weather prediction model output, where these data are judged to be accurate enough to assess the mission performance.

In addition to validating the wind vector performance, the geophysical model function, data flags, and error estimates shall also be validated.

The validation results shall be presented at a validation meeting at the end of the validation phase and published in the refereed literature.

### **11.2. [Requirement] Engineering Checkout Phase**

The mission shall support a 1-month engineering checkout phase during which no science or operational data are produced. The checkout phase is included in the total mission lifetime.

### **11.3. [Requirement] Calibration Phase**

The mission shall support a 3-month calibration phase for determining unknown static system parameters. During this time, operational and science data products may be produced but need not meet the performance requirements. The calibration phase is included in the total mission lifetime.

### **11.4. [Requirement] Validation Phase**

The mission shall support a 1-year phase for validating data product performance by the research and operations team. During this time, operational and research products are produced. A product upgrade and reprocessing of the science products may be required after the end of this phase. The validation phase is included in the total mission lifetime.

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